H-alpha Number Counts for Euclid &WFIRST

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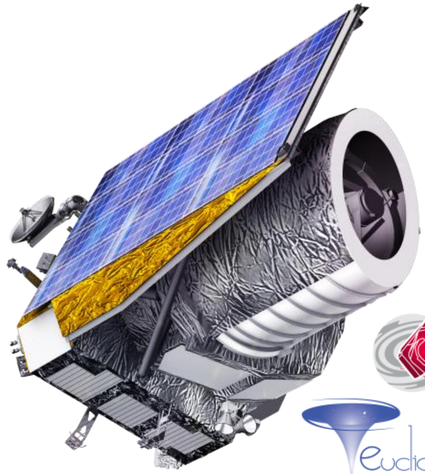
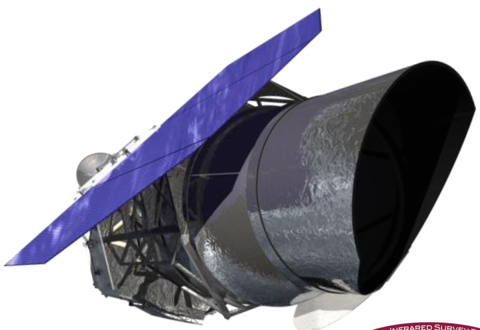




Why are we interested in Hα-emitting galaxies?

- Want to understand what is driving the accelerated expansion of the Universe?
- ESA Euclid and NASA WFIRST missions will **measure clustering of Hα-emitting galaxies**.
- Need to know how many we expect to see to optimise survey strategy for these missions.
- So, **how many Hα-emitting galaxies do we expect to see?**

Survey observing strategy ⇄ Number density of galaxies → Uncertainties on clustering measurements → Uncertainties on cosmological parameters

Optimise this… … to maximize this… …to minimise these!

The WFC3 Infrared Spectroscopic Parallels Survey (WISP)

"There is currently no better laboratory for predicting what these future missions can expect."
Colbert et al. (2013)

- **Slitless grism spectroscopy with HST WFC3** (Atek et al. 2010, 2011)
  - G141 (1.2-1.7μm, R~130) + G102 (0.8-1.2μm, R~210)
  - Detects H-alpha emitters out to z~1.5
  - Total area ~0.3 square degrees over ~400 separate fields (not all fields processed yet).

Hα detection with Euclid & WFIRST
- Euclid: 1.25 μm – 1.85 μm (0.9 < z < 1.8)
- WFIRST: ~ 1 μm – 2 μm (0.5 < z < 2)

- Number densities from WISP (0.7 < z < 1.5, flux limit of 2×10^{-16} erg $s^{-1} cm^{-2}$):
  - Colbert et al. (2013): ~6700 deg^{-2} (29 fields over area ~0.037 deg^2)
  - Mehta et al. (2015): ~6000 deg^{-2} (52 fields over area ~0.051 deg^2)

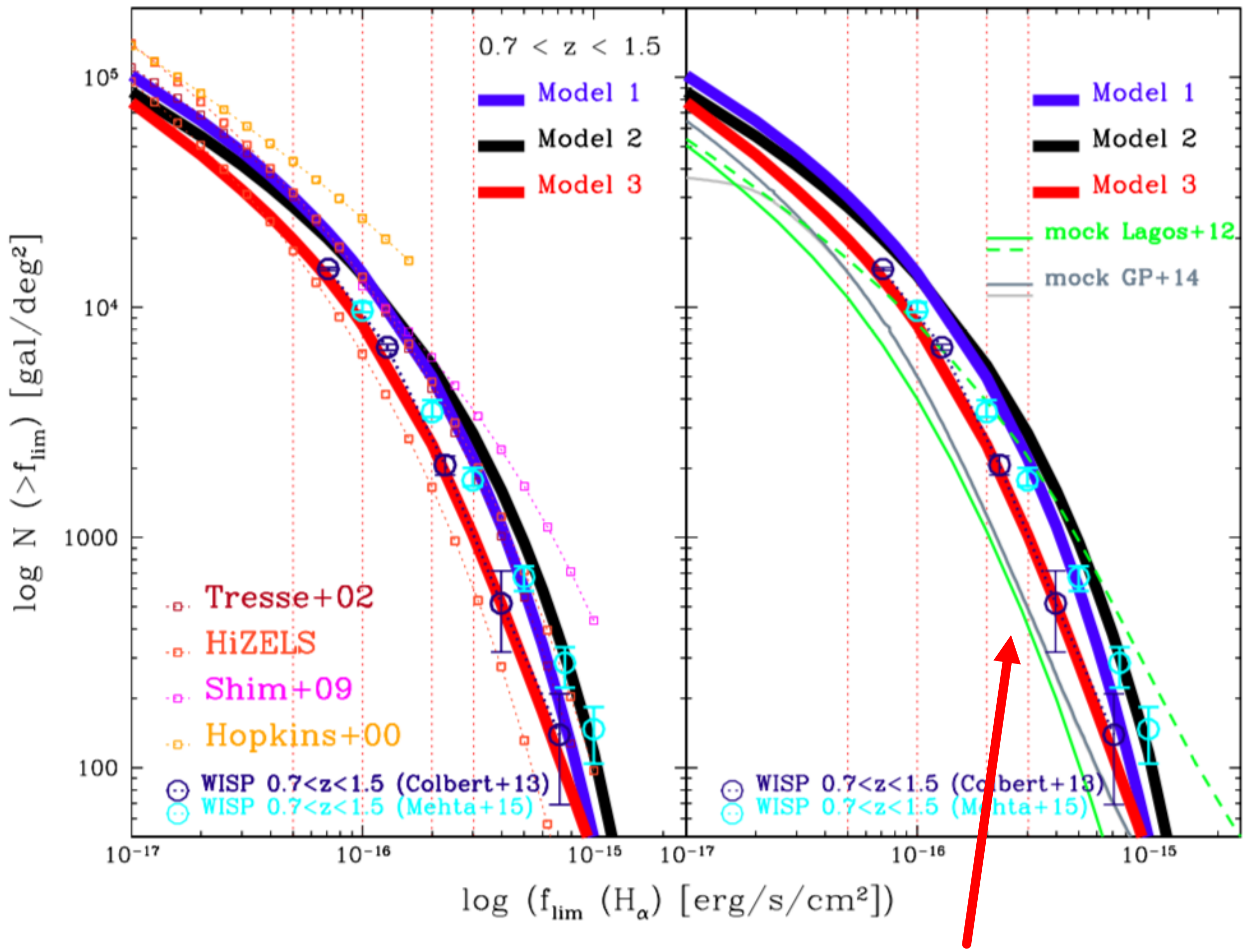
Estimates from Empirical Models

Pozzetti et al. (2016): three empirical models designed to fit H-alpha luminosity function.

Fit combinations of observations from WISP, HiZELS & HST+NICMOS grism survey.

Predictions:
Model 1: 3939 deg^{-2}
Model 2: 4819 deg^{-2}
Model 3: 2014 deg^{-2}

0.9 < z < 1.8
2 x 10^{-16} erg s^{-1} cm^{-2}
de-blended fluxes



Previous H-alpha mocks under-predicted counts

The **Galacticus** Galaxy Formation Model

- Open source **semi-analytical model** (Benson 2012)
    - solves coupled sets of differential equations governing astrophysical processes
    - can make multi-wavelength predictions (emission lines + photometry)
    - calibrated against local Universe observations (inc. stellar mass function).

Galacticus source code available from: **https://sites.google.com/site/galacticusmodel/**

- Emission line luminosities computed by interpolation over grid of models from photo-ionization model **CLOUDY** (Ferland et al. 2013)
    - interpolated over hydrogen density, metallicity of ISM, ionizing luminosities of HII regions (Hydrogen, Helium, Oxygen)
    - emission lines consistent with other galaxy properties

- Apply Galacticus to Millennium Simulation (Springel et al. 2005) to build lightcone spanning $0.5 < z < 2$ over 4 deg^2.
- Use default Galacticus parameters – do not further calibrate any parameters except vary dust attenuation.

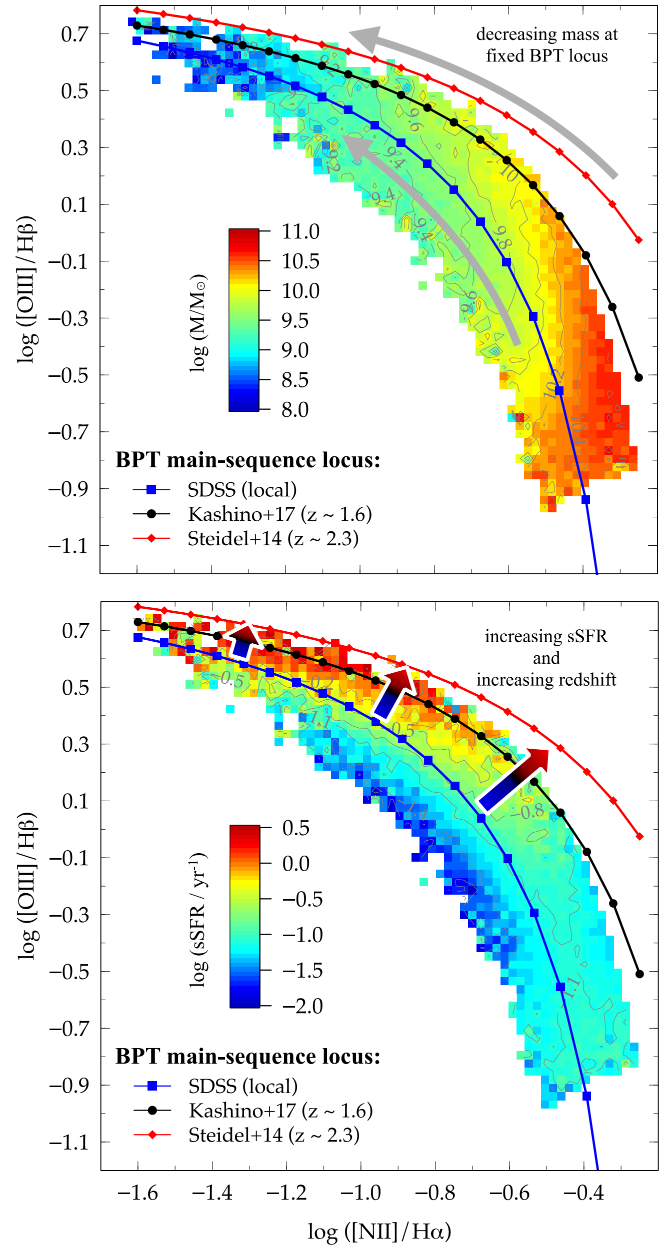
[NII] Contamination

- Masters et al. (2014) find [NII]/Hα ~ 0.1-0.2.

- [NII]/Hα ratios from Galacticus ~ 0.02.
- Do not calibrate Galacticus ISM gas metallicities so [NII] luminosities likely under-estimated.

- Masters et al. (2016) find strong correlation between stellar mass and sSFR and position in BPT diagram ([NII]/Hα vs. [OIII]/Hβ)
  - ➢ **only weakly dependent on redshift**
  - ➢ **stellar mass is dominant influence**.

- Assign [NII]/Hα ratio to Galacticus galaxies by cross-matching to SDSS catalogue used by Masters et al. (2016): using 5 nearest neighbours in stellar mass vs. sSFR space.

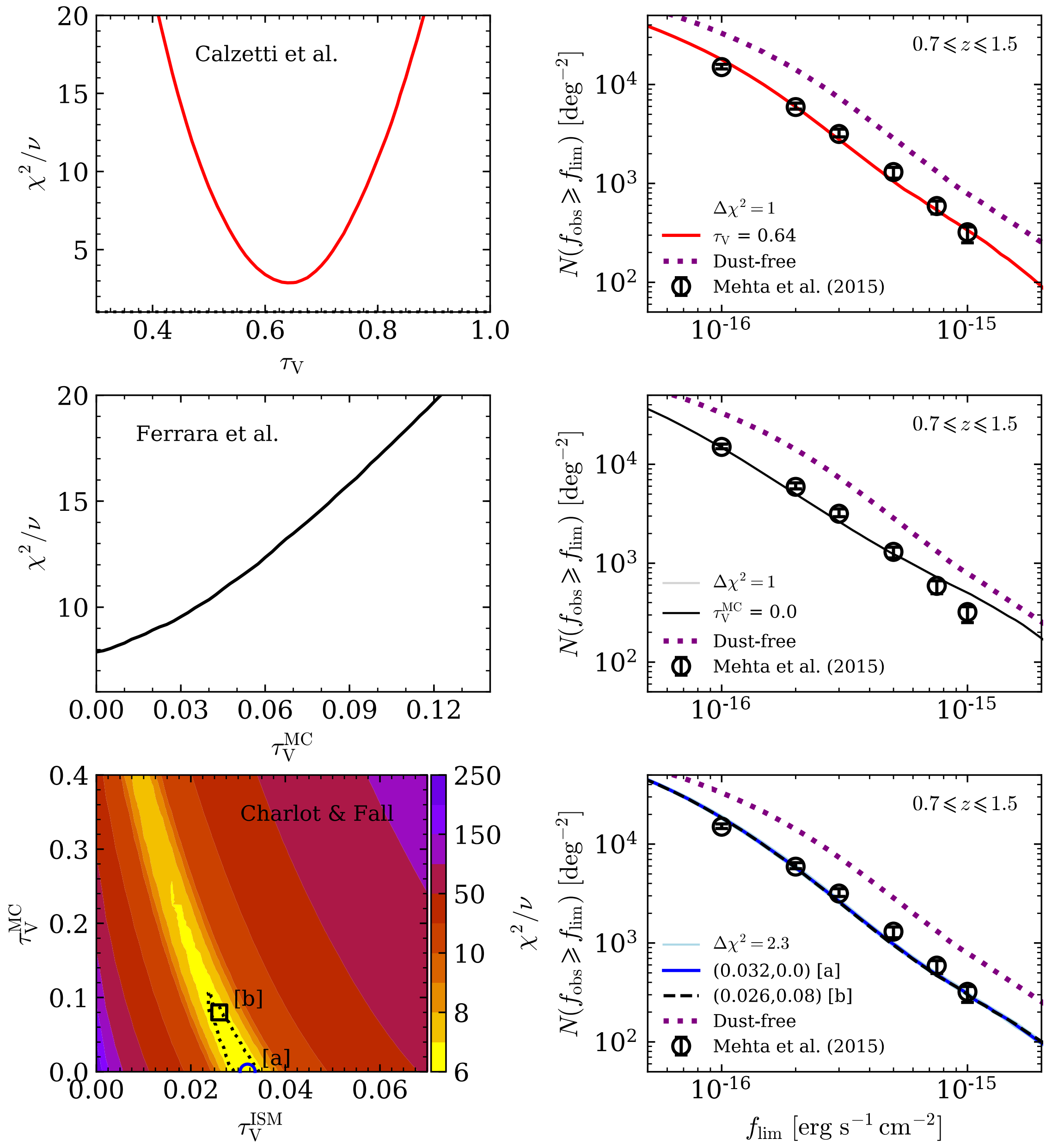


Faisst et al. (2018)

For further details on the modelling of [NII]/Hα ratios see Faisst et al. (2018).

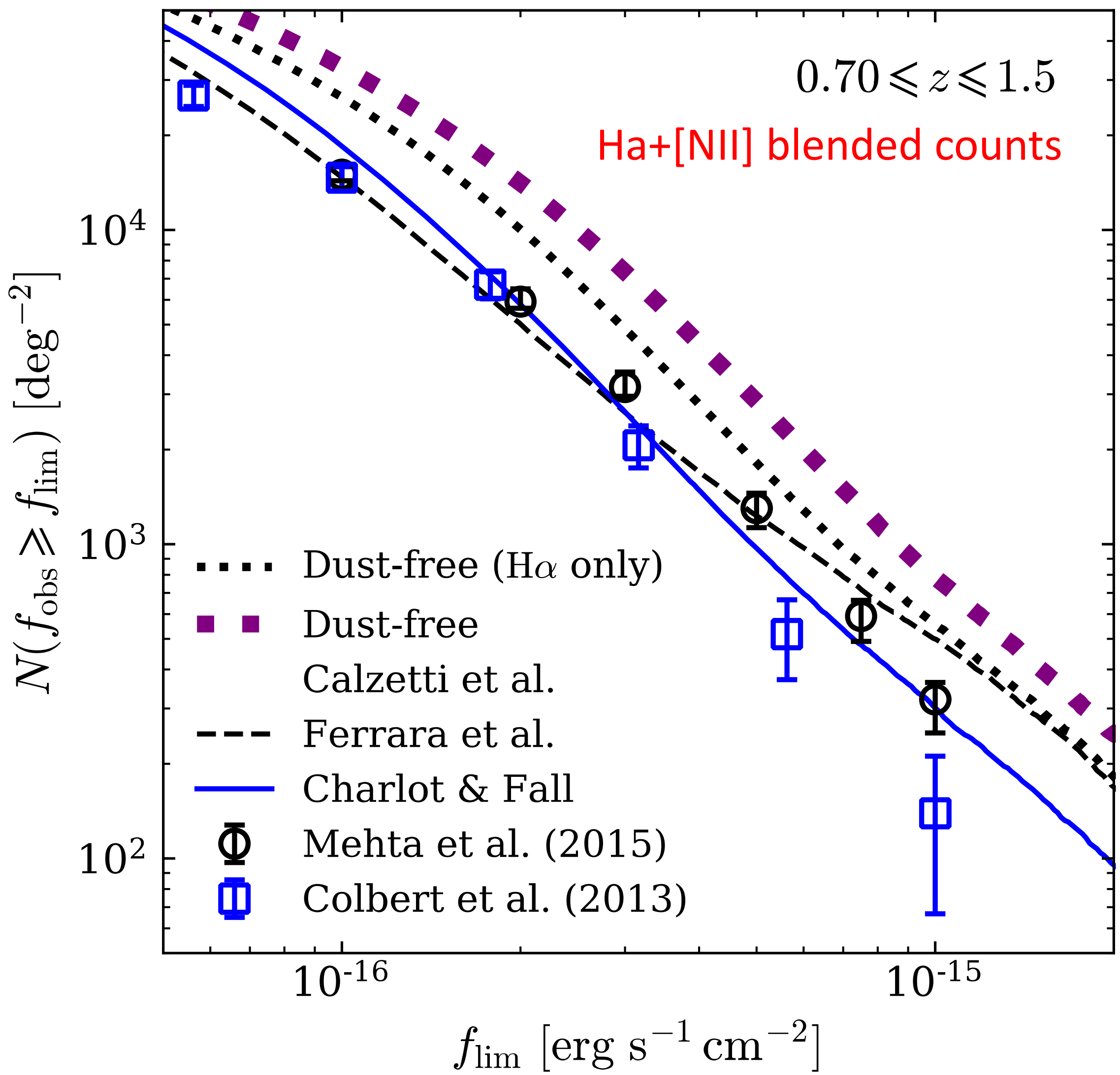
Dust Modelling

- Three dust methods:
  - ➢ **Ferarra et al. (1999)**: library of dust curves as function of various galaxy properties
  - ➢ **Charlot & Fall (2000)**: optical depth follows power law with wavelength
  - ➢ **Calzetti et al. (2000)**: empirical *dust screen* (global rescaling, function of wavelength)
- Use χ^2 minimisation technique to determine optical depths to match WISP counts from Mehta et al. (2016).



Comparison with WISP Counts

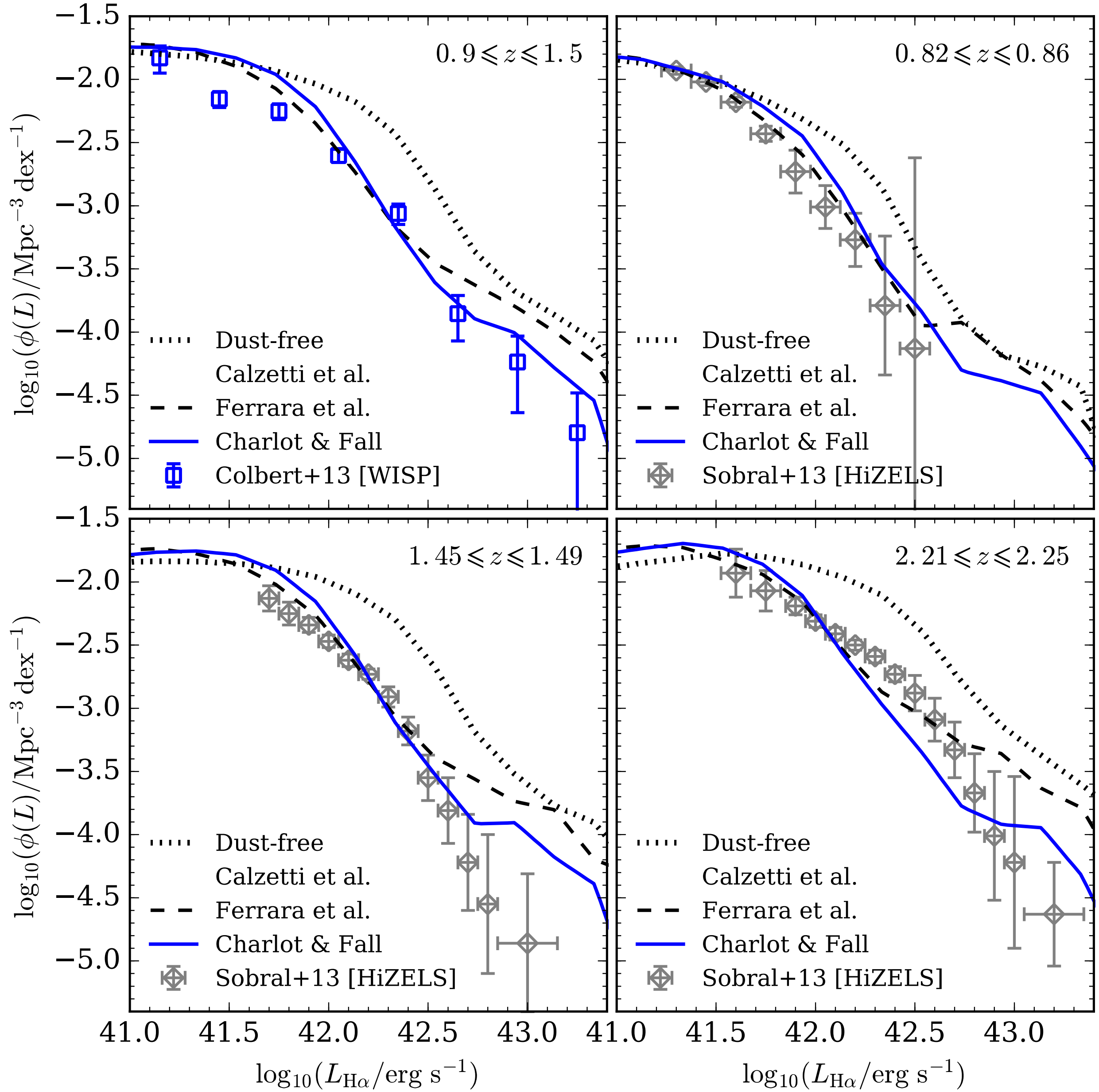
- Galacticus able to match WISP counts (previous mocks under-predicted counts).
- Calzetti et al. (2000) dust method leads to best match to counts (lowest χ^2).
- Counts affected by dust and [NII] contamination.



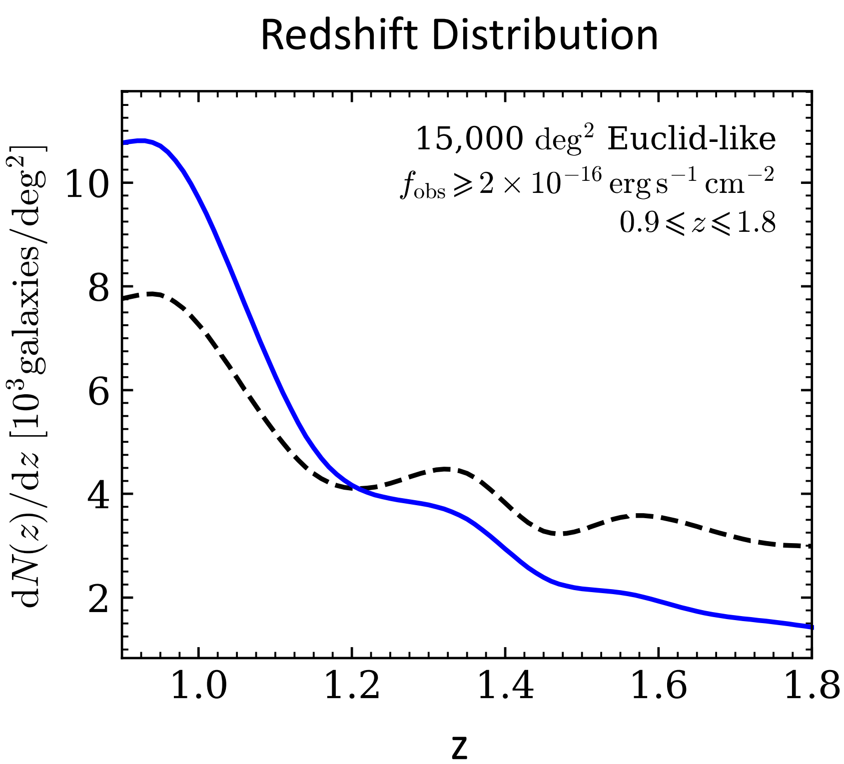
H-alpha Luminosity Function

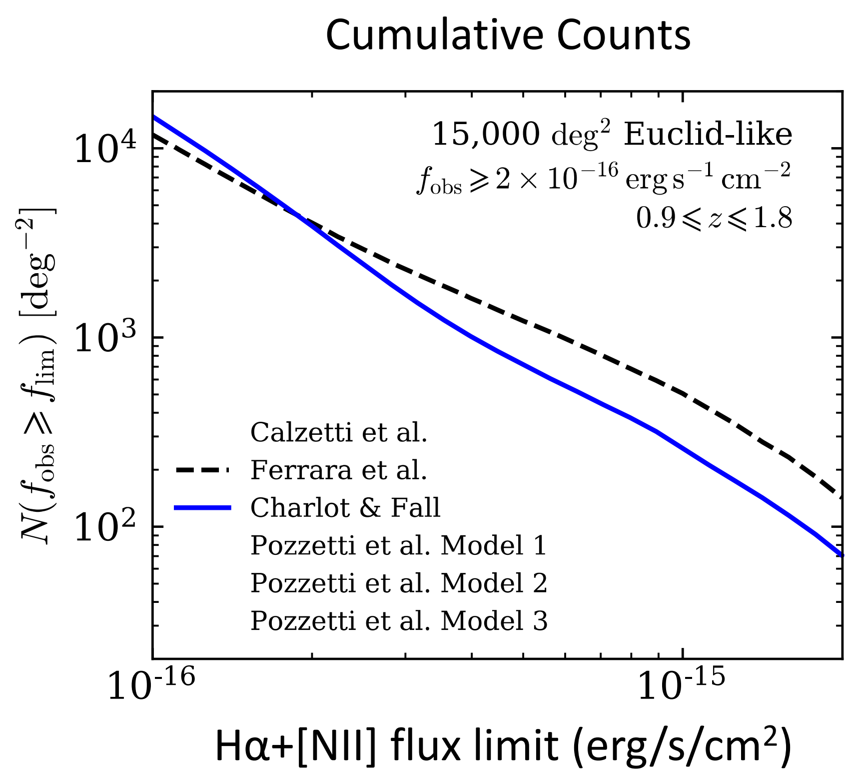
Dust-attenuated, rest-frame H-alpha luminosity function

- Good agreement with WISP and with HiZELS at low redshift.
- Poorer agreement towards higher redshifts (sample selection difference or further calibration of model needed?).



Counts for a Euclid-like survey

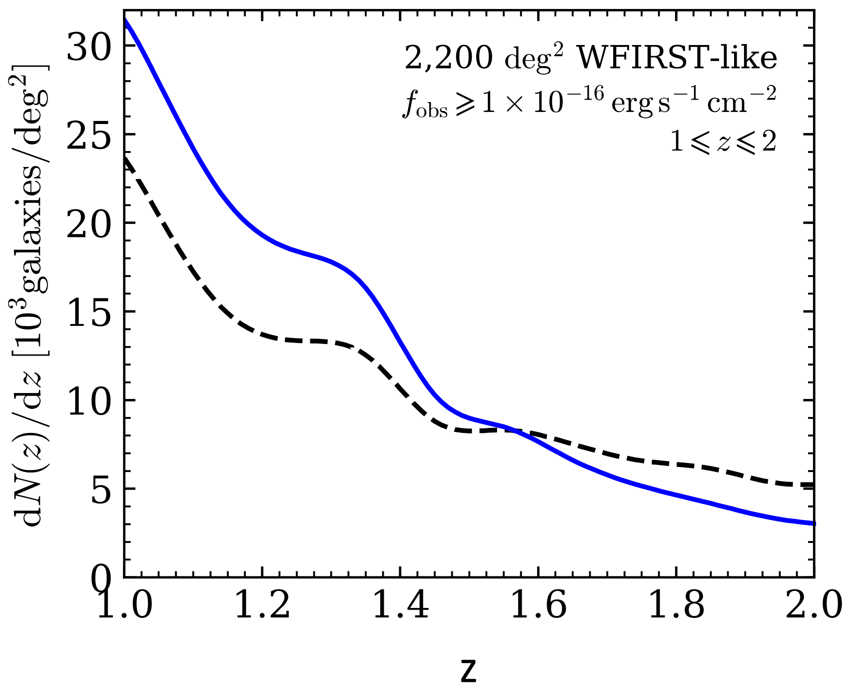




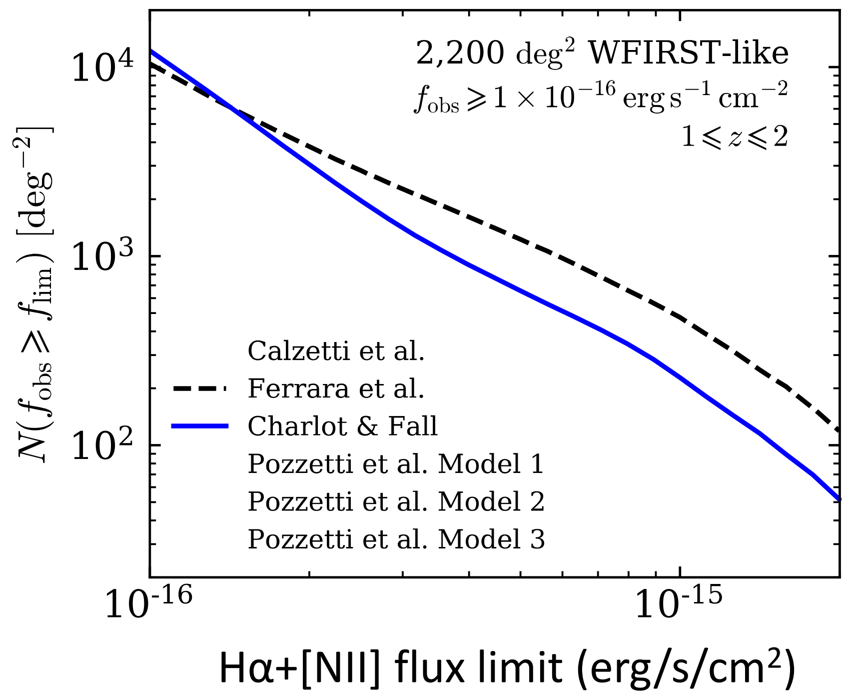
Flux Limit	Ferrara et al. (1999)	Calzetti et al. (2000)	Charlot & Fall (2000)
> 2 × 10^{-16} erg/s/cm^{-2}	4,036 ± 62 (deg^{-2})	4,849 ± 192 (deg^{-2})	3,884 ± 252 (deg^{-2})

Counts for a WFIRST-like survey

Redshift Distribution



Cumulative Counts



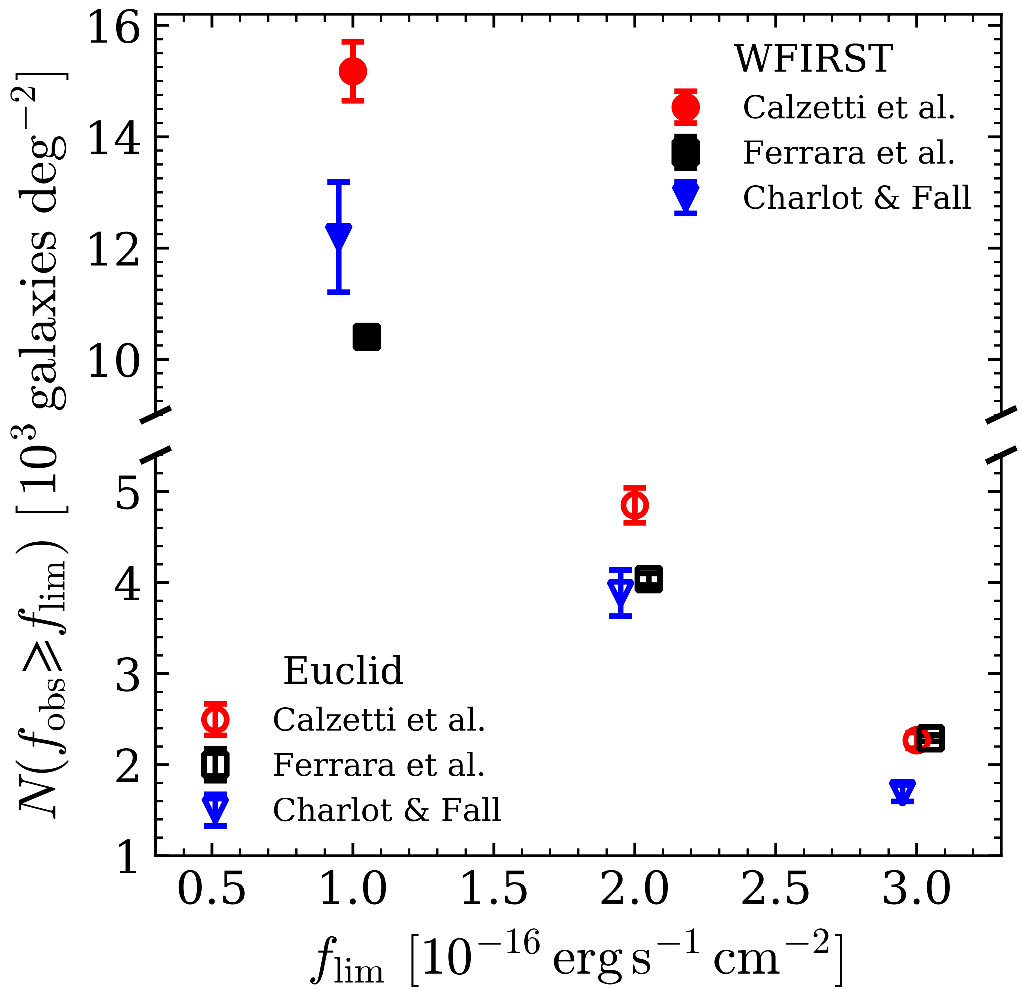
Flux Limit	Ferrara et al. (1999)	Calzetti et al. (2000)	Charlot & Fall (2000)
> 1 × 10^{-16} erg/s/cm^{-2}	10,403 ± 138 (deg^{-2})	15,176 ± 528 (deg^{-2})	12,195 ± 987 (deg^{-2})

Predicting Euclid/WFIRST counts

- Scatter in Galacticus predictions:
  → **5%—30%** for Euclid-like
  → **20%—50%** for WFIRST-like
- Comparable or smaller scatter compared to empirical models.

- Galacticus predictions more **robust** — physical galaxy formation model with properties calculated self-consistently.

- Galacticus counts most consistent with **model 3** from Pozzetti et al. (2016).



Summary

- Knowledge of number density of Hα-emitting galaxies essential for **optimizing survey strategy**.

- Counts of Hα-emitting galaxies from **Galacticus lightcone able to reproduce observed counts** from WISP survey.

- Galacticus number densities of:
  - ➢ 3,800–4,800 deg^{-2} for $f>2 \times 10^{-16}$ erg/s/cm^{-2} over $0.9 < z < 1.8$ (~Euclid)
  - ➢ 10,400–15,200 deg^{-2} for $f>1 \times 10^{-16}$ erg/s/cm^{-2} over $1 < z < 2$ (~WFIRST)

- Galacticus counts consistent with Model 3 of Pozzetti et al. (2016), but with smaller scatter for a Euclid-like survey. Comparable scatter for deeper WFIRST-like survey.

- Galacticus Hα number counts published in **Merson et al. (2018) arXiv:1710.00833**.

- <u>Ongoing work:</u>
  - ➢ Extensive calibration of Galacticus using MCMC chains (A. Benson).
  - ➢ Examination of bias of Hα-emitting galaxies as function of redshift and luminosity.
  - ➢ Provision of mocks with SEDs (continuum + emission lines) for testing emission line detection (collaboration with WISP).

EXTRA SLIDES

The Wide Field Infrared Survey Telescope (WFIRST)

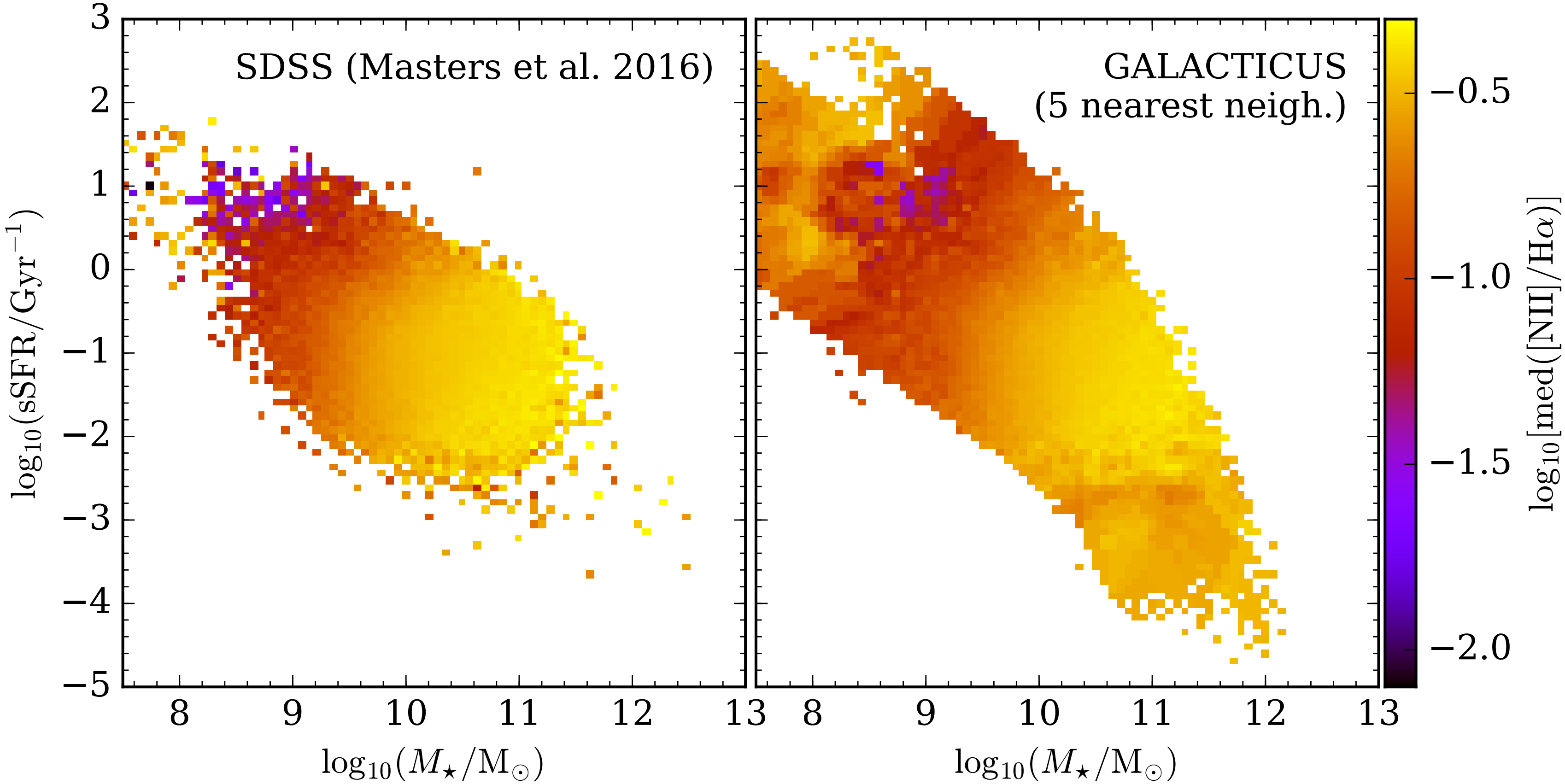
- WFIRST is a **dark energy + exoplanet mission** with **wide-field capabilities.**
- WFIRST is a space-based **2.4m telescope** that would provide **Hubble-like imaging** resolution (0.11’’/pixel) but over **100x more** sky: WFIRST FoV = 0.28 deg^2 (100x FoV of HST and JWST)
- Nominally a 5yr mission (inc. 25% GO), but can be extended to 10yrs (100% GO).

- WFIRST **High Latitude Survey (HLS)** will be optimized for dark energy studies:
  - ➢ Nominally 1.5 years over ~2,000 deg^2,
  - ➢ Redshift survey (slitless spectroscopy): ~22M ELGs: Hα ($1 < z < 2$) and [OIII] ($2 < z < 3$),
  - ➢ Imaging survey: shape information for ~380M galaxies in YJH+F184.
- Designed to be **synergistic with DESI/Euclid/LSST**.
- Data will be made public worldwide straight away, i.e. **NO PROPRIETARY PERIOD**.

www.wfirst.gsfc.nasa.gov www.wfirst-hls-cosmology.org

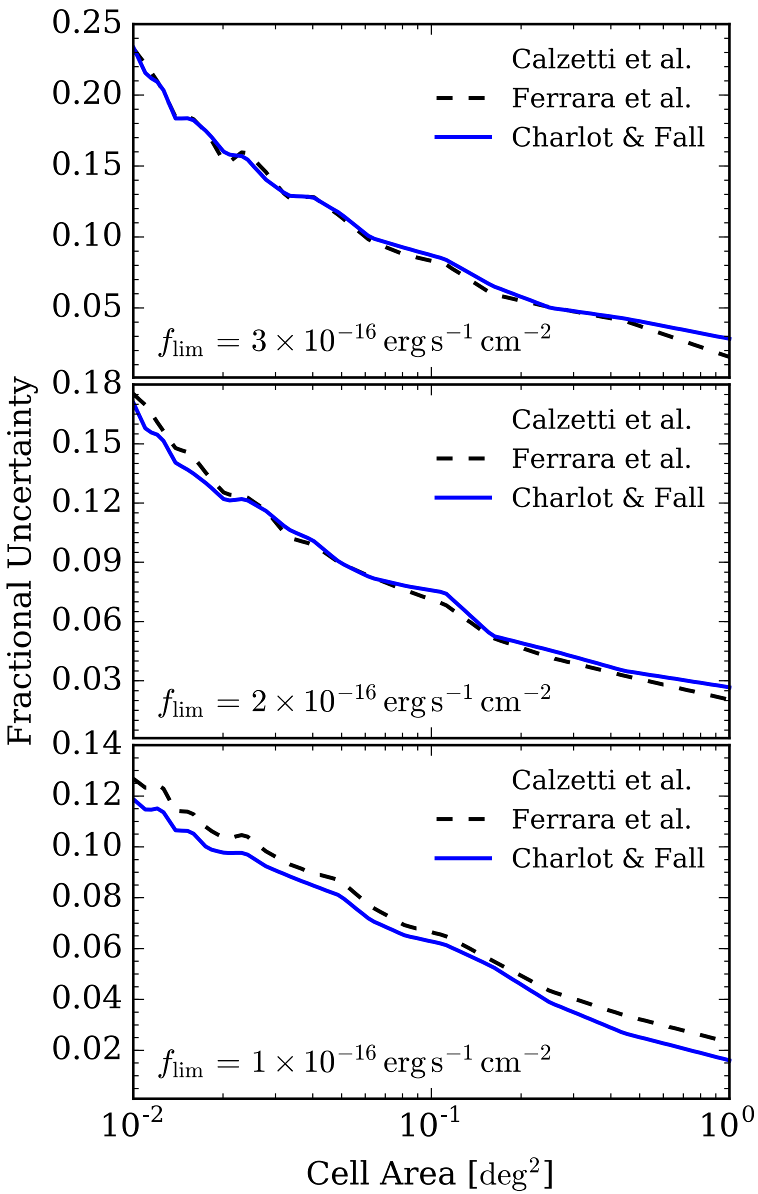
Cosmology with the HLS Science Investigation Team 2017 Report: **arXiv1804.03628**.

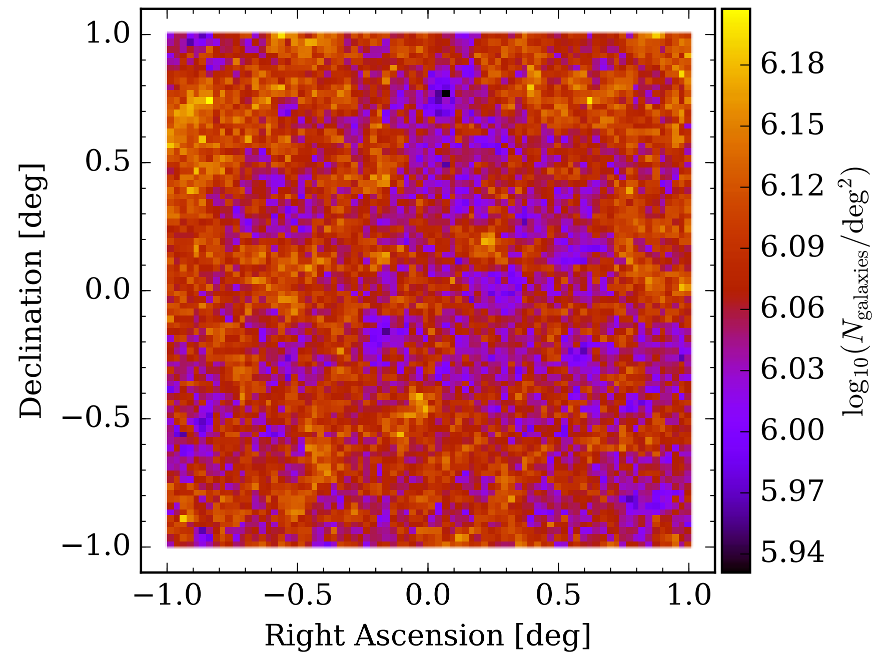
Modelling [NII] Contamination



- [NII]/Hα value assigned to Galacticus using 5 nearest neighbours from Masters et al. (2016) SDSS catalogue.
- Negligible IMF correction needed: Galacticus uses Chabrier et al. (2003) and Masters et al. (2016) used Kroupa et al. (2001).

Impact of Cosmic Variance



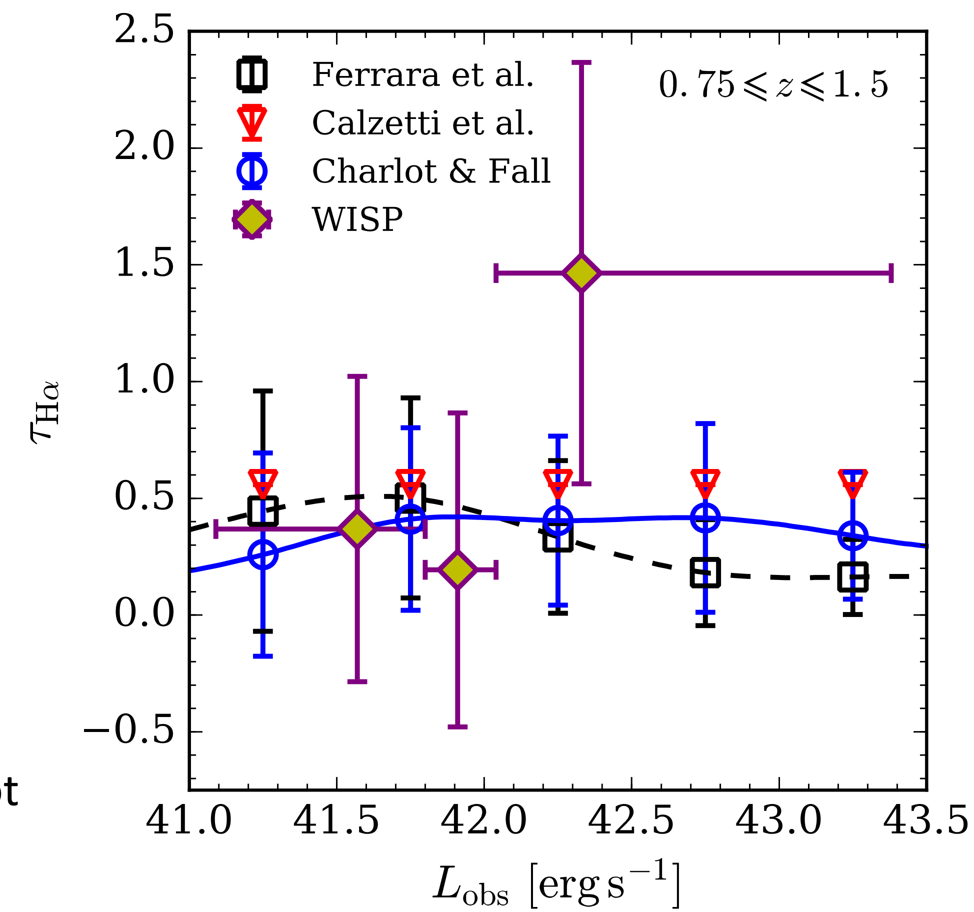


- Split lightcone footprint in to N×N cells and compute counts for each cell.
- Fractional uncertainty = std.dev./mean counts (over N×N cells) at particular flux limit.
- **For full lightcone, cosmic variance impacts counts at ~2-3% level.**
- For ~0.05 deg^2 (area used by Mehta+2015) cosmic variance impacts at ~8-9% level.

Optical Depth Comparison

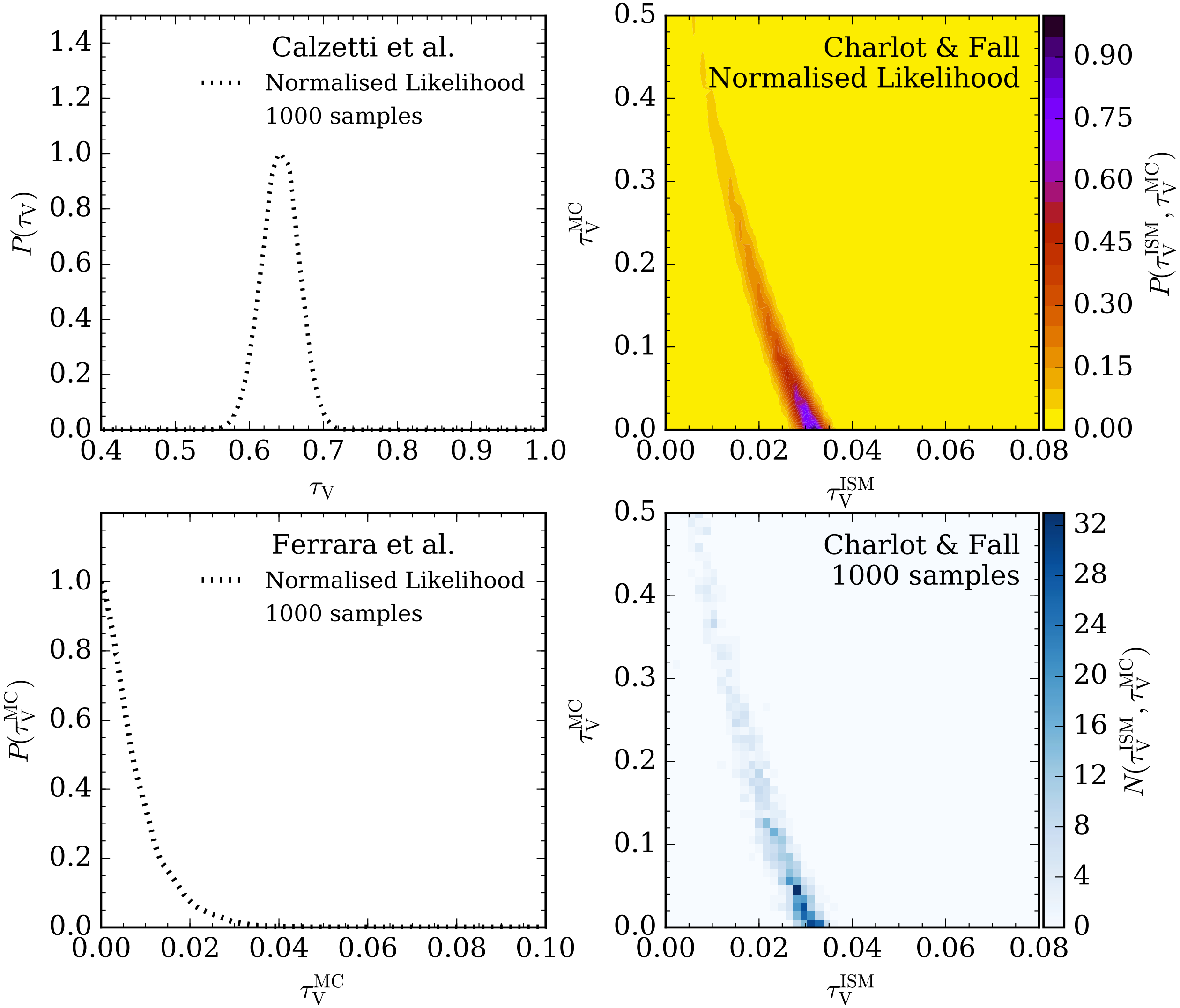
$$\tau_{\mathrm{H}\alpha} = -\ln\left(\frac{L^{\mathrm{att}}_{\mathrm{H}\alpha}}{L^{0}_{\mathrm{H}\alpha}}\right)$$

- WISP optical depths from Domínguez et al. (2013).
- Galacticus optical depths consistent for faint luminosities.
- Increasing optical depth towards bright luminosities not reproduced by in Galacticus.

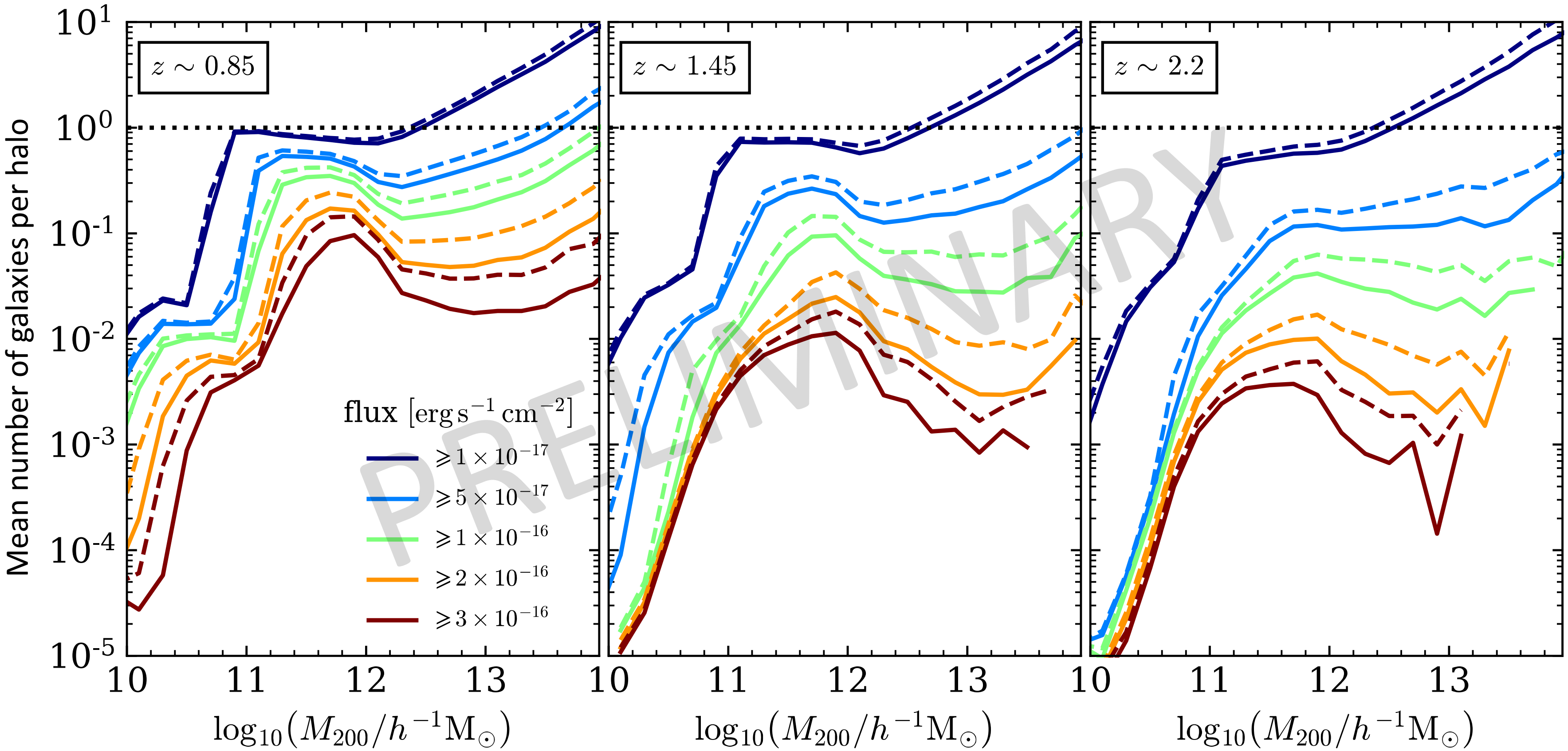


Predicting Euclid/WFIRST counts

- Use χ^2 minimisation results to construct likelihood for dust parameters.
- Use Monte-Carlo sampling to sample dust likelihoods 1000 times → generate 1000 optical depths for each dust method.
- Apply each optical depth → generate 1000 realisations for redshift distribution and counts.



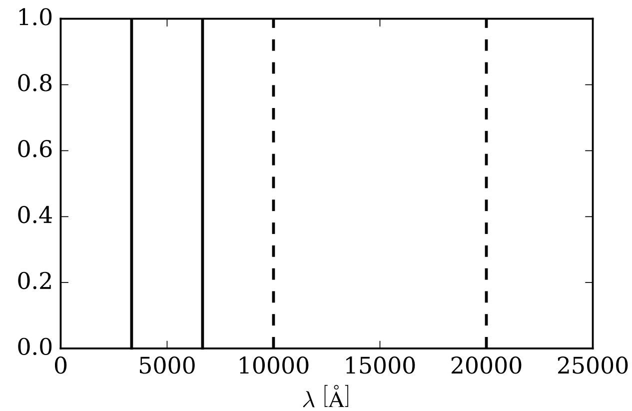
Ongoing work: Hα galaxy HODs



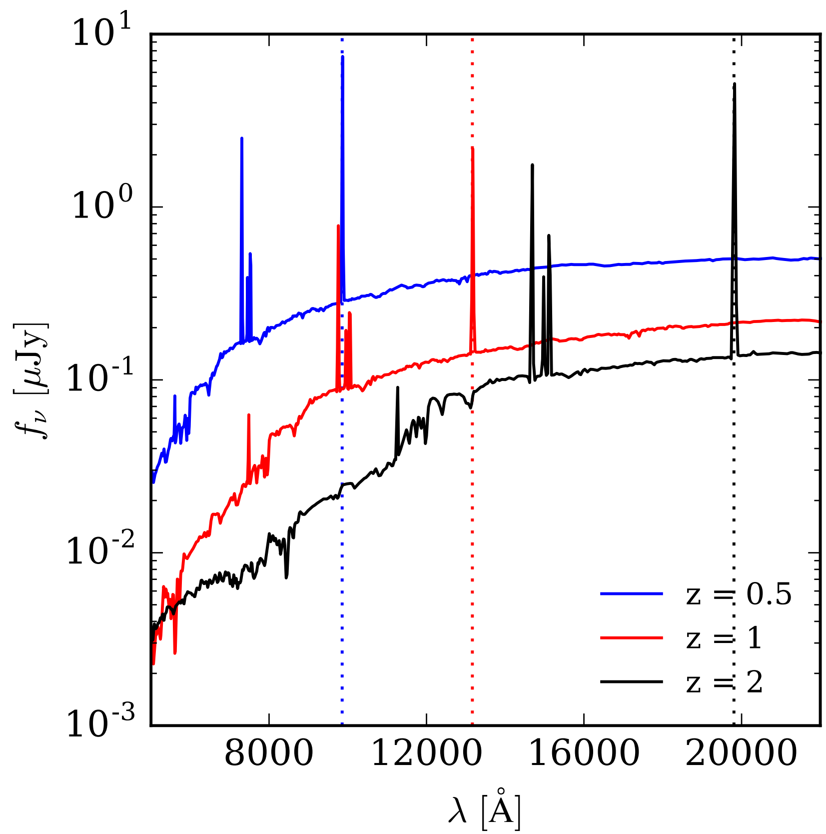
- At z~1.45 for f>2 × 10^{-16} erg/s/cm^{-2} expect one Hα-emitting galaxy per ~100 DM halos.
- Next step: use HODs and LFs to predict Hα galaxy bias as function of redshift and luminosity.

Merson et al. (in prep.)

Ongoing work: Spectral Energy Distributions



- Continuum from array of top-hat filters.
- Resolution limited by resolution of outputs from stellar population synthesis model.



- Emission lines added on top:
  - Gaussian profiles
  - Amplitude set by luminosity
  - Profile width estimated using velocity dispersion (or set to fixed width in km/s).
- Example spectra to test emission line detection for Euclid & WFIRST.